



Improving the representation of terrestrial ecosystem processes in Earth system models to increase the quality of climate model projections and provide the scientific foundations needed to inform DOE's energy decisions

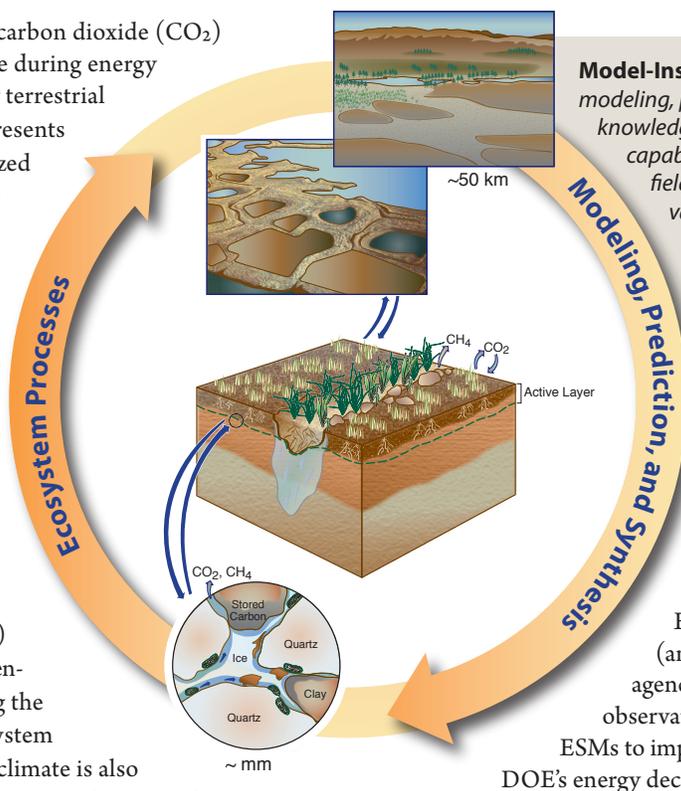
A significant fraction of the carbon dioxide ( $\text{CO}_2$ ) released to the atmosphere during energy production is taken up by terrestrial ecosystems. This carbon “sink” represents an important but poorly characterized buffer for offsetting the greenhouse gas effects of anthropogenic  $\text{CO}_2$  emissions. Also unclear are the effects of related processes such as nutrient, water, and energy cycling—in addition to climate variability and change—on that uptake. Resolving the terrestrial biosphere's role in the global carbon cycle is consequently a high priority for the Terrestrial Ecosystem Science (TES) program within the Department of Energy's (DOE) Office of Biological and Environmental Research (BER). Understanding the mechanisms and dynamics of ecosystem processes in the face of a changing climate is also essential for improving the representation of terrestrial ecosystems and climate feedbacks in Earth system models (ESMs). TES supports research to advance fundamental understanding of terrestrial ecosystems and their roles in a changing climate.

## Research Approach

TES research employs a systems approach to understand ecosystems over multiple scales for representation in models (e.g., single-process models, ecosystem models, and the Community Earth System Model). This emphasis on the capture of advanced process understanding has three goals: (1) advance fundamental understanding of ecosystem dynamics, (2) improve process representation in coupled models to increase the sophistication of model projections, and (3) encourage the comparison

### TES focuses on ecosystems and ecological processes that are:

- Globally or regionally significant,
- Expected to be sensitive to climate change, and
- Insufficiently understood or inadequately represented in models.



**Model-Inspired Research.** TES research uses modeling, prediction, and synthesis to identify knowledge gaps and uncertainties in predictive capabilities. These activities, in turn, inspire field observational experiments that validate models and provide crucial data for their improvement. This cyclical, integrative approach is applied across scales—from the molecular to ecosystem level. [Lawrence Berkeley National Laboratory]

of model results against observations or other datasets to inform future research directions.

As part of BER's Earth and Environmental Systems Sciences Division (EESDD), TES coordinates with EESDD's climate modeling program (and research activities in other federal agencies), ensuring that experimental and observational results are incorporated into ESMs to improve climate projections and inform DOE's energy decisions.

## Building on BER's Legacy of Experimental Innovation

Terrestrial ecosystems respond to changes at varying scales of time and space, with some long-term effects emerging slowly over many years. Understanding these responses often requires observation or manipulation over extended time periods.

BER has a distinguished history of designing, testing, and implementing leading-edge experimental approaches to study the long-term relationships between climate and atmospheric composition and terrestrial ecosystems. The Free-Air  $\text{CO}_2$  Enrichment (FACE) method of controlling elevated  $\text{CO}_2$  (and ozone) concentrations within ecosystems is

**NGEE-Tropics.** Tropical forests such as the Amazon (pictured) cycle more carbon and water than any other ecosystem and are estimated to be Earth's largest carbon sink. A critical question is whether these forests will continue to offset a large fraction of anthropogenic carbon emissions or become carbon sources. [Lawrence Berkeley National Laboratory]





### Spruce and Peatland Responses Under Climatic and Environmental Change.

*SPRUCE*, an ecosystem-scale manipulation study in northern Minnesota, is revealing insights about climate change effects on the structure and function of spruce and peatland areas. The experiment (partially visible here) increases atmospheric CO<sub>2</sub> to more than twice current concentrations and increases air and soil temperatures as much as 9°C to discover ecosystem responses to predicted changes in climate.

**Inset:** Leaf gas exchange is measured as part of the *SPRUCE* study.

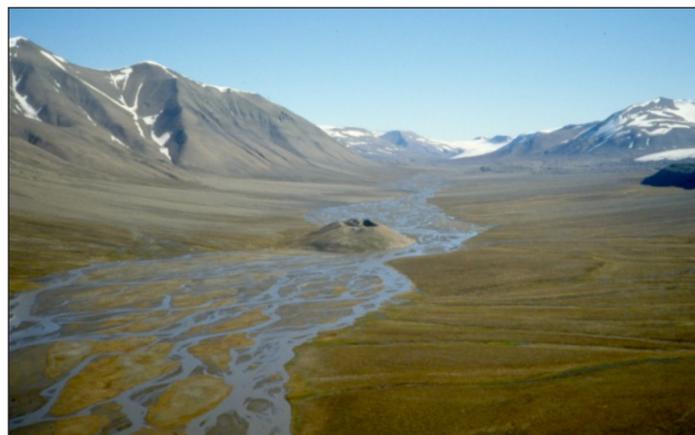
[Both images, Oak Ridge National Laboratory]

one such success story. The FACE approach, developed by BER, is now used throughout the world in a wide range of ecosystems. Results of FACE experiments are invaluable in forecasting both future atmospheric CO<sub>2</sub> concentrations and the role of terrestrial ecosystems in future climates.

Large-scale, long-term experimental precipitation and temperature manipulation experiments also were pioneered by BER. These studies provide vital knowledge about the effects of changing precipitation on the structure and function of terrestrial ecosystems, as well as the influence of ecosystems on climate. Current and future investments—including BER’s innovative concept for coupling models with experimental and observational campaigns in the next-generation ecosystem experiments (NGEE)—will build on this legacy and reshape the approach to long-term ecosystem studies through iterative, model-inspired research activities. Two such projects, NGEE–Arctic and NGEE–Tropics, are examining how Arctic terrestrial ecosystems and tropical forest ecosystems will respond to climate change. TES investments also provide management and support infrastructure for the AmeriFlux Network, the interagency activity coordinating long-term CO<sub>2</sub> (and energy) flux measurements across North America. TES research will continue to navigate the forefront of interactions between terrestrial ecosystems and a changing climate.

### Program Priorities

TES research focuses on understanding both the ecological effects of climate change and ecosystem feedbacks between the biosphere



**NGEE–Arctic.** Permafrost stores massive quantities of carbon in frozen soil. Release of this carbon as permafrost thaws in a warming Arctic represents a potential tipping point for climate change. [University of Alaska, Fairbanks]

and atmosphere. Through model-inspired, hypothesis-driven observations; experimental manipulations; and large-scale, long-term field studies, the program seeks to understand and explain the mechanisms and processes controlling primary production, carbon cycling, biogeochemistry, belowground processes, disturbance, and other important interfaces to terrestrial ecosystems. The resulting information contributes to EESSD’s strategic goal to develop, test, and simulate process-level understanding of atmospheric systems and terrestrial ecosystems extending from the bedrock to the vegetative canopy-atmosphere interface. Ultimately, this understanding is captured as predictive relationships that drive coupled regional and global models and informs future research and energy decisions.

### Research Funding

TES supports BER mission-oriented ecosystem research at universities, national laboratories, and other research institutions through regular peer-reviewed, hypothesis-driven, and proposal-based competitions. Funding opportunities are posted at [www.grants.gov](http://www.grants.gov).

### BER’s TES activity:

Seeks to enhance the representation of terrestrial ecosystem processes in ESMs, thereby

- Improving the quality of climate-model projections and
- Providing the scientific foundation of solutions for DOE’s most pressing energy and environmental challenges.

### Program Managers and Websites

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#### Terrestrial Ecosystem Science

[tes.science.energy.gov](http://tes.science.energy.gov)

#### NGEE–Arctic

[ngee-arctic.ornl.gov](http://ngee-arctic.ornl.gov)

#### NGEE–Tropics

[ngee-tropics.lbl.gov](http://ngee-tropics.lbl.gov)

#### SPRUCE

[mnspruce.ornl.gov](http://mnspruce.ornl.gov)

#### AmeriFlux Network

[ameriflux.lbl.gov](http://ameriflux.lbl.gov)

#### Earth and Environmental Systems Sciences Division

[science.osti.gov/ber/Research/eessd](http://science.osti.gov/ber/Research/eessd)

#### DOE Office of Biological and Environmental Research

[science.osti.gov/ber](http://science.osti.gov/ber)

#### DOE Office of Science

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#### U.S. Department of Energy

[energy.gov](http://energy.gov)